

## CRYOGENIC AND THERMAL ASPECTS OF THE SIRTF WARM LAUNCH CONCEPT

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### ABSTRACT

A fundamentally new concept is being explored for cryogenic operation of the Space Infrared Telescope Facility (SIRTF). In this concept, the helium dewar and instruments would be launched at liquid helium temperature while the telescope and external radiation shields are at room temperature. Once on-orbit, the telescope and the radiation shields would be cooled radiatively to about 70 K. Helium vapor is then used to bring the telescope down to its final operating temperature of 5.5 K. We present a design which meets SIRTF requirements and discuss its merit.

### INTRODUCTION

The Space Infrared Telescope Facility (SIRTF) is planned by NASA to be a unique observatory that offers an unprecedented sensitivity and imaging capability in the infrared portion of the spectrum from 4 to  $180\mu\text{m}$ .<sup>1</sup> In order to optimize the design of this challenging mission, a new low mass "warm launch" baseline design has been developed.<sup>2</sup>

In traditional "cold launch" infrared telescope designs (IRAS and ISO), the mirror and instrument package are enclosed within an open-ended cryogenic dewar and are cooled to 2 K when the dewar is filled with liquid helium before launch. In this design, the dewar vacuum vessel must enclose the entire facility, requiring a large, heavy structure for a telescope the size of SIRTF (0.85 m diameter primary mirror).

The current "warm launch" design for SIRTF offers a great savings in mass by reducing the size of the vacuum vessel. In this design, only the instrument package and helium tank are enclosed within the dewar. The primary and secondary mirrors are outside of the dewar and at room temperature when the facility is launched. A thin outer shell and vapor cooled radiation shield surround the telescope and provide thermal isolation when in space. The outer shell is shielded from solar radiation by a solar panel, which allows the outer shell to radiate its heat to space and cool to about 50 K soon after launch. The primary and secondary mirrors (telescope assembly) are initially cooled to about 50 K through a heat switch connected to the outer shell. Then the heat switch is opened, and cold vapor from the helium dewar cools the telescope to below 5 K within a few weeks.

A detailed mechanical and thermal design study demonstrates the feasibility of the warm launch design and highlights some technical challenges to be overcome.

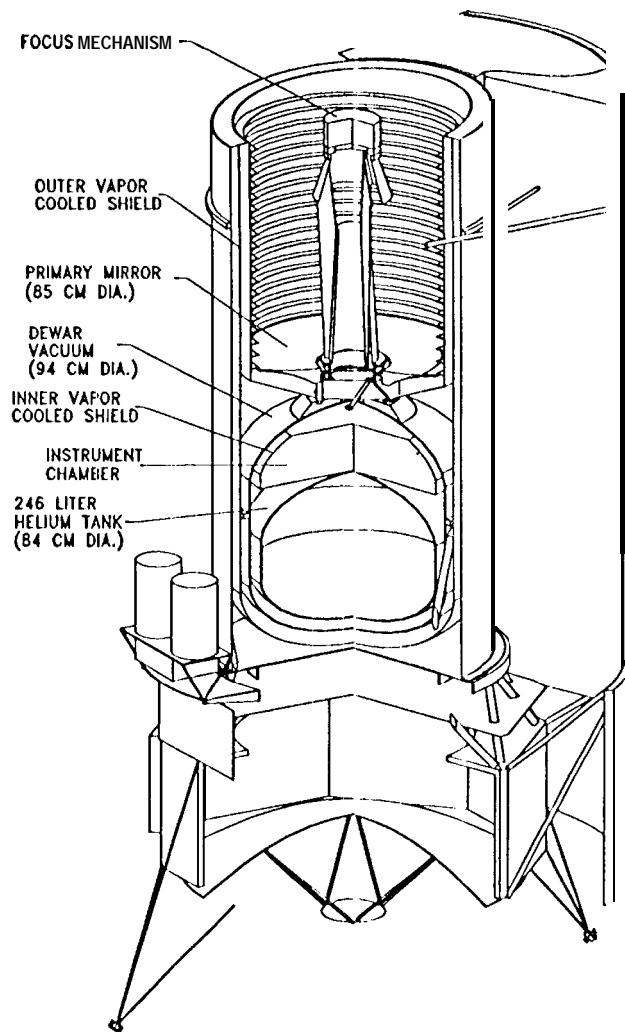


Fig. 1. SIRTIF internal configuration,

## OBSERVATORY CONFIGURATION

The configuration of the observatory is shown in figure 1. Low-thermal conductivity struts mount the Cryo-Telescope Assembly (CTA) to the top of the spacecraft which is temperature controlled near 300 K. The solar panel and solar panel shield are supported by low-conductivity struts from the top and bottom of the outer shell. The solar panel shield has a radiator at the top of the observatory. Radiation to space keeps the shell shield at about 180 K, allowing the outer shell to reach 60 K or less. The spacecraft shield, between the spacecraft and the CTA, includes a radiator to cool it below 130 K.

The internal configuration of the CTA has two main parts: the telescope, and the dewar. The telescope is mounted to the top of the dewar vacuum shell on struts. The Dewar contains the instrument chamber and the liquid helium tank. A bolted flange near the middle of the dewar outer shell permits disassembly. The telescope and dewar are thermally connected.

The instrument chamber is an aluminum enclosure containing the science instruments. The instrument chamber is supported from the helium tank by struts. Copper straps thermally couple the instrument chamber and the 1.4 K helium bath. The helium tank is supported from the dewar vacuum vessel by struts made of gamma alumina/epoxy composite. Another set of gamma-alumina struts support the dewar from the bottom of the CTA.

The vacuum cover or "cork" is located on the top of the dewar vacuum vessel between the instruments and the telescope. After launch it is opened to admit light to the instrument

chamber. The cover may incorporate a window to permit visible light testing of the focal plane while the cover is closed. The vacuum cover must be vacuum tight at room temperature in order to maintain the integrity of the dewar vacuum vessel before launch. Once in space, the vacuum cover needs only to prevent the instrument from becoming contaminated before the telescope cools.

The telescope and dewar are surrounded by a lightweight outer shell. The outer shell is closed at the bottom. Before launch, the outer shell is closed at the top by a dust cover, and the observatory is kept under an inert gas such as dry nitrogen to prevent atmospheric contamination of the mirrors and low emissivity surfaces.

The observatory has two vapor-cooled shields, plus the dewar vacuum shell, which also acts as a vapor-cooled shield. The inner vapor-cooled shield (IVCS) is mounted between the helium tank and the dewar shell. The outside of the IVCS is wrapped with multilayer insulation (MLI). The outer vapor-cooled shield (OVCS) is mounted between the dewar and the outer shell. The OVCS is supported from the outer shell by gamma-alumina struts. All surfaces from the dewar shell to the outer shell are gold coated for low emissivity.

A vapor vent line is connected between the helium tank and vent valves on the outer shell. In orbit, helium vapor flows through the vent line and cools the IVCS, the dewar vacuum shell and telescope, the OVCS, the dewar support struts, the instrument wires, and the outer shell. On the ground, the vapor flow cools the IVCS and instrument wires.

### Observatory Cooldown

Before launch, the outer shell, the OVCS, the dewar vacuum shell, and the telescope are at room temperature. During the initial cool-down in space, a heat switch conducts heat from the dewar vacuum vessel and the telescope assembly to the outer shell. This heat switch may be either a removable metal link or helium gas purged into the assembly before the "cork" is opened. The heat switch accelerates the cooldown of the telescope and dewar vacuum shell to about 70 K. After this initial cooldown, the thermal connection between the telescope and the outer shell is broken. Vapor cooling is then used to bring the observatory to its operating temperature.

## THERMAL DESIGN

### Requirements

There are three driving thermal requirements: The helium bath must beat a temperature of 1.4 K or less, the telescope must be at 5.5 K or less, and the liquid helium must last at least 2.5 years.

The current SIRTf mission plan places the facility in a heliocentric orbit trailing the earth that eliminates the Earth as a heat source and allows a thermal design that puts the observatory behind a solar shield.

### Internal Thermal Design

The liquid helium tank has a low-emissivity gold coating and the IVCS is covered with MLI to reduce the heat load on the dewar prior to launch. Gamma-alumina struts are used throughout the design to provide high stiffness supports with low thermal conductivity. The outside surface of the telescope baffle, both sides of the OVCS and the inner surface of the outer shell have low emissivity gold coatings. The instrument wires and various supports are thermally coupled to the vapor vent line at several places to reduce the heat load into the telescope assembly.

A porous plug liquid-vapor separator in the vent line contains the liquid helium while maintaining the instrument temperature at 1.4 K. A particular challenge is to design a porous plug that will operate at both the high flow rate encountered prior to launch, and at the low flow rate after the initial cooldown.

### External Thermal Design

To maximize the helium lifetime, the observatory outer shell temperature must be as low as possible. The sources of heat to the outer shell are the spacecraft and the solar panel.

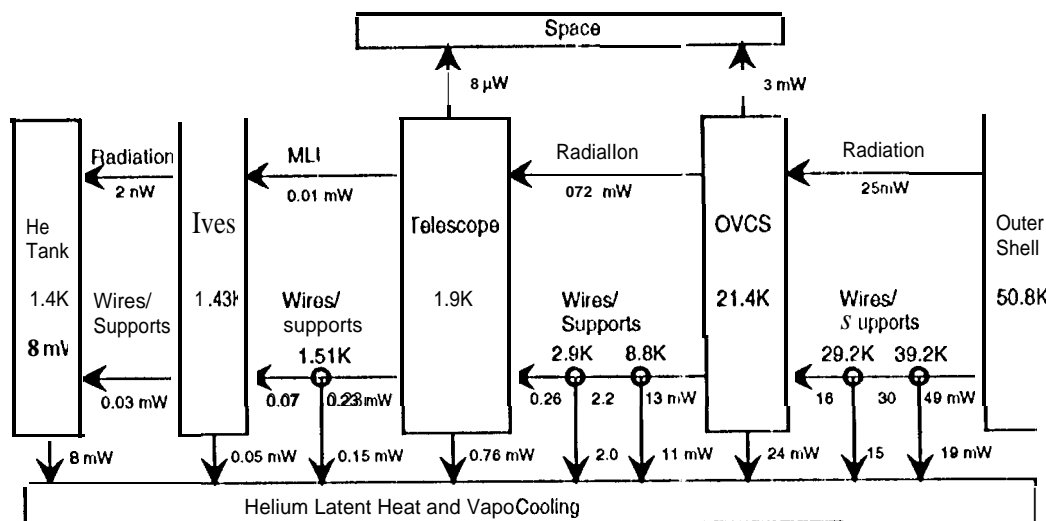


Fig. 2. SIRTf internal temperatures and heat flows configuration

A shield is mounted between the spacecraft and observatory and another shield is mounted between the solar panel and the outer shell. The shields are covered with MLI to decrease the emissivity of their surfaces. The wedge shaped solar panel shield curves away from the outer shell in order to improve its view factor to space and to improve the thermal isolation between it and the outer shell.

The cold side of the outer shell (the side away from the sun) has a high-emissivity coating. The outer shell temperature is set by the thermal balance between the heat adsorbed from the heat sources and the heat radiated to space from the cold side. The temperature difference between the hot side and the cold side is about 5 K.

The spacecraft is maintained near 300 K by louvers, MLI, heaters and the electronics heat dissipation. The solar panel has 86 percent of its area covered with solar cells and 14 percent covered with optical solar reflectors. The OSRs reduce the solar panel temperature, typically 350 K.

## THERMAL MODEL

The SIRTf baseline design has been developed with the aid of an integrated Microsoft Excel spreadsheet model that couples a mechanical configuration spreadsheet to a thermal balance calculation, enabling many parametric trade studies to be performed quickly. Further static and transient thermal calculations were performed with the same equations and parameters using *Mathematica*.

The thermal design solves for the temperatures of twelve nodes, assuming that the helium bath temperature is 1.4 K. All radiative and conductive heat flow calculations, except heat transfer to space, were increased by a factor of 1.2 to allow for unexpected design changes. Heat flow through MLI at low temperature was modeled using the data from Spradley et al.<sup>3</sup>

### Static Thermal Performance

The temperatures and heat flow data inside the observatory are shown in figure 2, assuming gold coatings with 0.015 emissivity. Note that the heat flow into the helium tank is dominated by the instrument power dissipation, 8 mW. The OVCS would not be necessary in this design except to provide sufficient performance when the dewar outer wall and telescope assembly are at 300 K before launch. The helium flow rate during this time is approximately 13 mg/s, compared with 0.4 mg/s when in space. This design presents a difficult requirement on the porous plug liquid-vapor separator, which must either operate over a very wide dynamic range, or include a valve to switch between two porous plugs of different areas. Future designs may improve the ground performance of the system in order to reduce the required porous

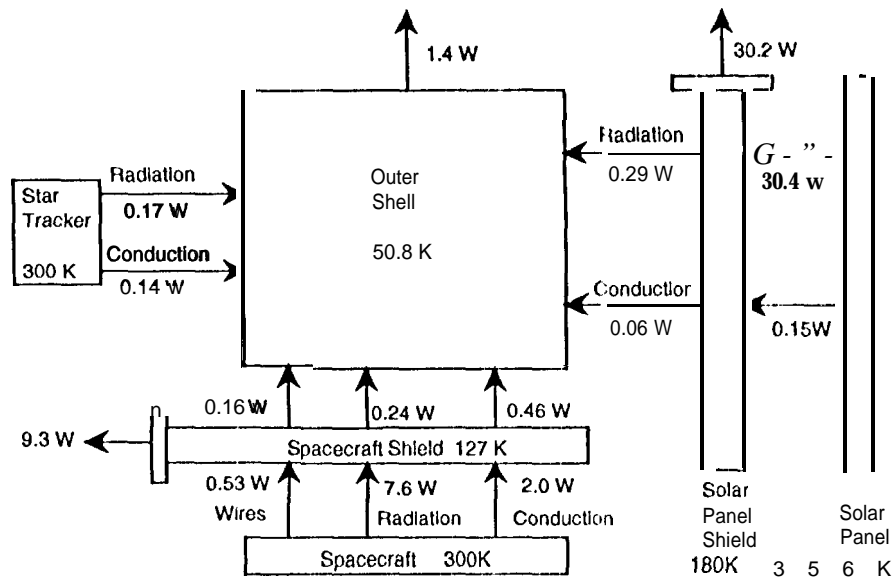


Fig. 3. SIRT external temperatures and heat flows. View factors for the radiative heat flow calculations were derived using the NEVADA Monte-Carlo ray tracing program.

plug dynamic range.

The current baseline design achieves a lifetime of 2.5 years using 250 liters of  $^4\text{He}$ . This is primarily due to the low outer shell temperature, about 50 K. Figure 3 shows the temperatures and heat flow data outside the outer shell. Note that most of the heat is intercepted by the solar panel shield and the spacecraft shield.

The telescope and dewar outer wall is primarily cooled by the helium vapor. The boil-off rate is mainly determined by the instrument power dissipation. Figure 4 shows a plot of the telescope temperature vs. instrument power for instrument power dissipations from 0 to 16 mW. The telescope is below the required temperature (5.5 K) when the instrument power is above 5 mW.

The performance of the baseline design depends strongly on the ability to fabricate surfaces with low emissivity coatings. Figure 5 shows the telescope temperature for several values of emissivity. Note that adequate performance is achieved for emissivities less than 0.025, an achievable goal.

### Transient Thermal Performance

The warm launch design depends on radiation to space to cool the telescope to below 50 K. The first 30 days of operation were modeled assuming the nominal values for emissivity and instrument power. Figure 6 shows the various temperatures as a function of time. The outer shell temperature drops rapidly to about 50 K within several days of launch. After seven days, the telescope has reached 50 K, and the heat link to the outer shell is opened. At that point, it takes about two weeks for the helium vapor to cool the telescope to its operating temperature.

Figure 7 shows the Helium boil-off rate and figure 8 shows the helium consumption as a function of time for the initial 25 days in space. Approximately 16 L of liquid helium are expended before the telescope cools. Another 8 L of liquid helium will be consumed during the 24 hour pre-launch hold, requiring about 250 L of liquid helium for the 2.5 year mission.

### BENEFITS AND CHALLENGES OF THE WARM LAUNCH DESIGN

There are several advantages of the warm launch design. Placing the telescope outside of the cryogen tank permits the aperture of the telescope to be increased without increasing

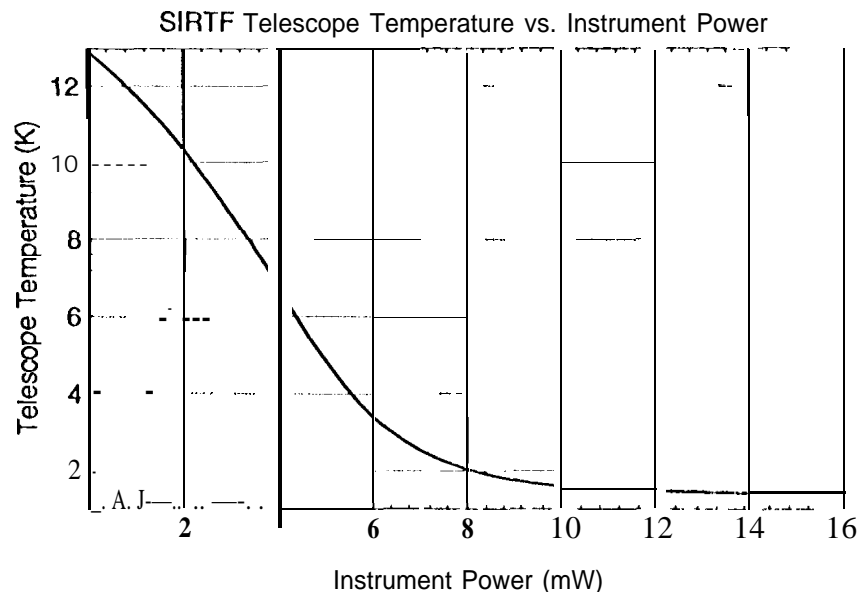


Fig. 4. Telescope temperature vs. Instrument power with tile low  $\epsilon$  surfaces having emissivity values of 0.015.

the size (and mass) of the dewar, which should allow a larger telescope to be launched on a given launch vehicle. Because the telescope is launched warm, a cryogenic shake test of the telescope is no longer required; it appears that there are other potential savings and simplifications in test and integration as well. The warm-launch architecture is a step towards the future, because it can readily be adapted to telescope apertures larger than the 0.58 m size of SIRTF and its cold-launch predecessors.

The warm launch design also presents several challenges. The porous plug liquid-vapor separator will need to operate over a wide dynamic range. The vacuum cover, or cork, must seal a large diameter vacuum opening in the dewar at low temperatures. Low emissivity surfaces must be fabricated and maintained in order for the telescope temperature to be low enough. A particular challenge to the optical design is to maintain alignment between the instrument chamber and the telescope assembly over a wide range of telescope temperatures.

Other design concepts under consideration include locating the instrument chamber outside of the dewar vessel under the telescope assembly where it would be at room temperature during the launch. The instruments would then be cooled by superfluid helium provided by a fountain effect pump. This design further reduces the mass of the overall system but makes pre-launch instrument testing far more difficult.

## ACKNOWLEDGMENTS

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*Jet Propulsion Laboratory*

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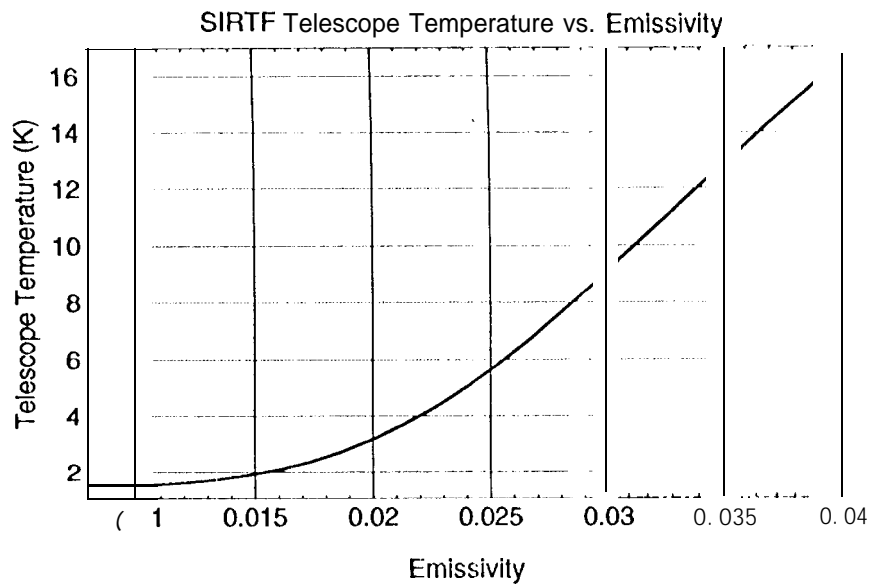


Fig. 5. Telescope temperature vs. emissivity with the instrument power fixed at 8 mW.

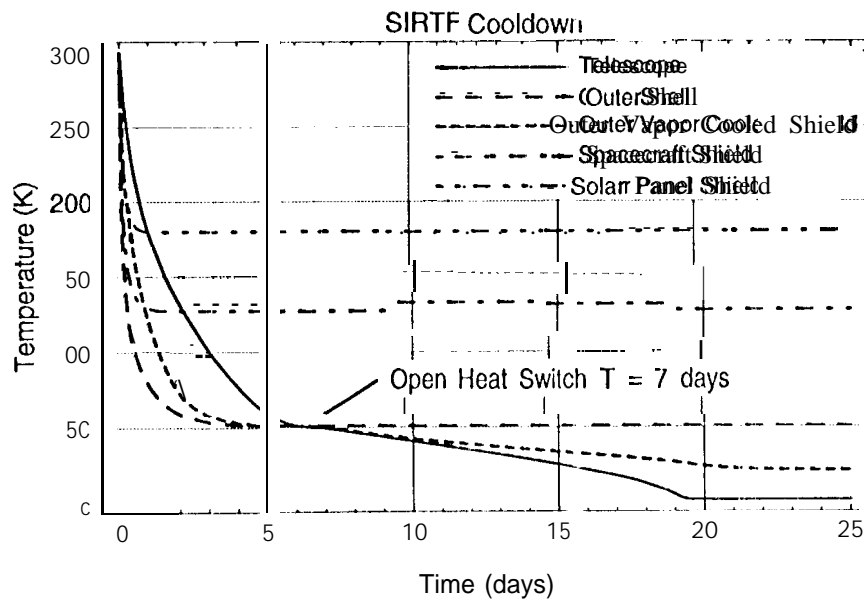


Fig. 6. Telescope temperature vs. time for the nominal instrument power (8 mW instrument power and 0.015 emissivity surfaces).

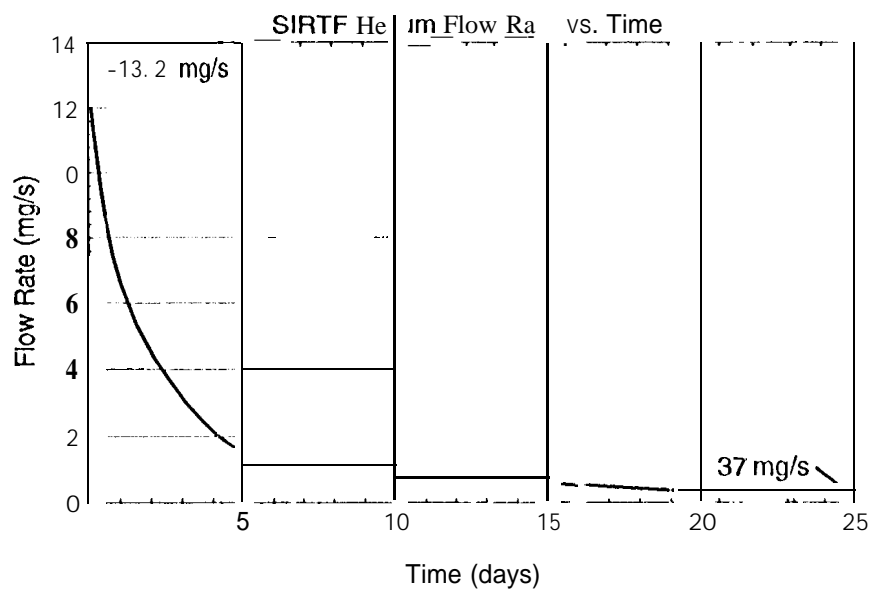


Fig. 7. Helium boil-off rate for the first 25 hours in space assuming 8 mW instrument power and 0.015 emissivity surfaces

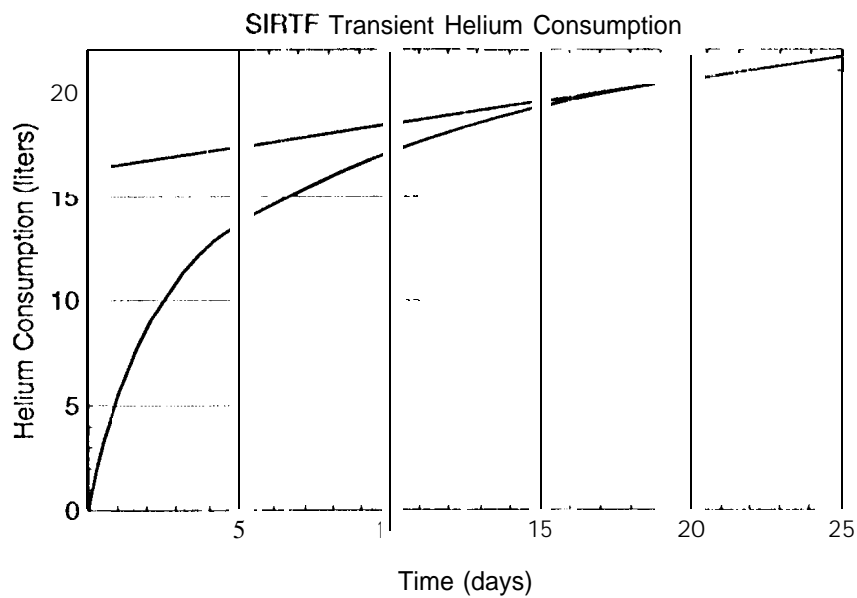
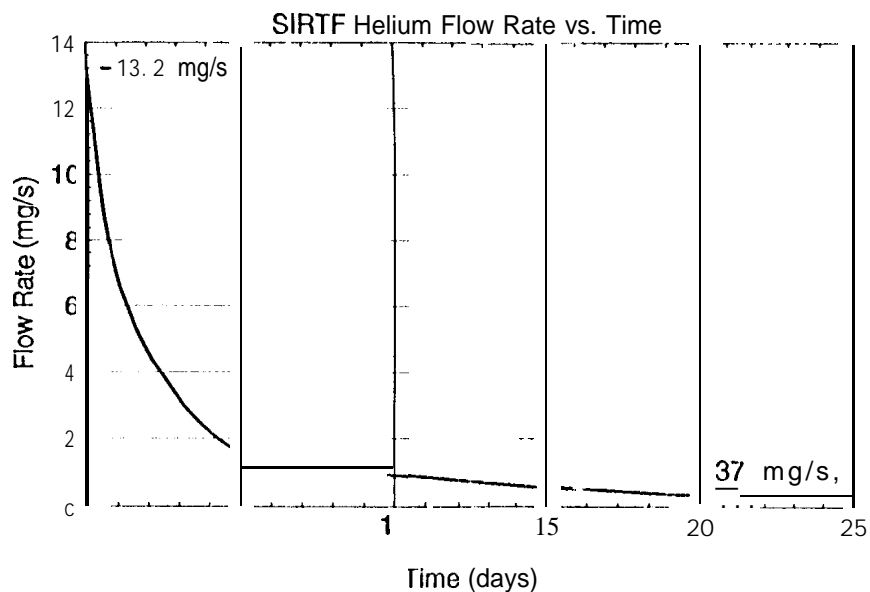
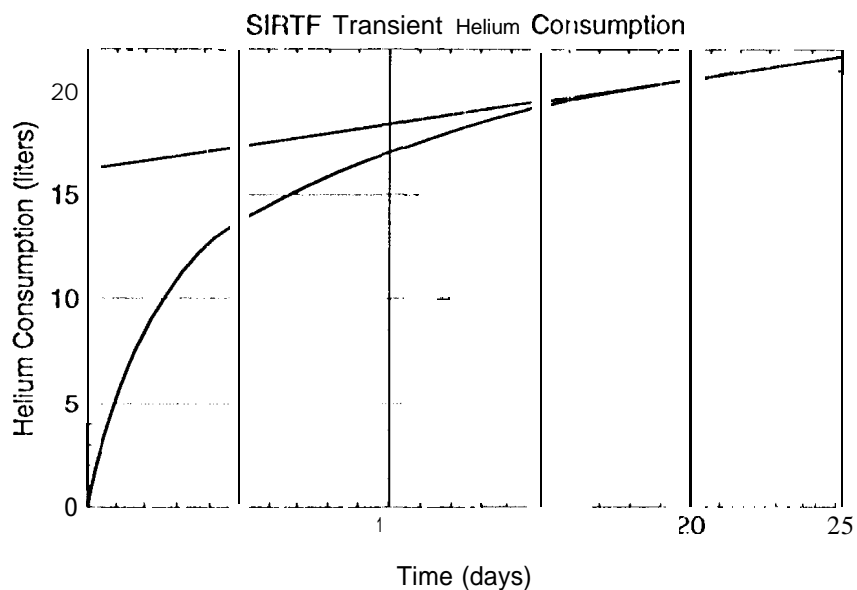


Fig. 8. Lower Curve shows the helium consumption vs. time for the first 25 days in space with the nominal instrument power (8 mW) and emissivity (0.015). The upper line has a slope representing the steady state helium boil off rate after the initial transient has settled.





**Fig. 7.** Helium boil-off rate for the first 25 hours in space assuming 8 mW instrument power and 0.015 emissivity surfaces



**Fig. 8.** Lower Curve shows the helium consumption vs. time for the first 25 days in space with the nominal instrument power (8 mW) and emissivity (0.015). The upper line has a slope representing the steady state helium boil off rate after the initial transient has settled.